Sea-thru: A Method For Removing Water From Underwater Images

Pranjal Singh, Siddharth Maurya, Chandra Shekhar

IIT Hyderabad

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Proposed Model

- **Direct Signals** and **Back-scatter** are control by different coefficients (the old model** considered both coefficients same).
- Both the coefficients have dependencies on factors other than the optical properties of water (the old model** ignored them).

** *The* **Old Model** *means the algorithm was derived for atmosphere and neglected the strong wavelength dependency of light underwater.*

Underwater image formation

Underwater image formation is governed by:

$$I_c = D_c + B_c \tag{1}$$

where,

c is R, G, B color channel
$\boldsymbol{I_c}$ is *Image captured*
$\boldsymbol{D_c}$ is the *Direct signal*
$\beta_{\boldsymbol{c}}^{\boldsymbol{D}}$ is the wide-band(RGB) coefficient
$\boldsymbol{B_c}$ is the *Back-scatter*
$\beta_{\boldsymbol{c}}^{\boldsymbol{B}}$ is the back-scatter coefficient

contd...

- Image I_c is the image captured by the camera with distorted colors.
- *Direct signal* D_c contains the information about the scene but in attenuated form.
- *Back-scatter* B_c is an additive signal that degrades the image due to the reflection of light from particles present in the water.

where,

The components *Direct signal* D_c and *Back-scatter* B_c are governed by two distinct coefficients β_c^D and β_c^B, which are wide-band(RGB) attenuation and back-scatter coefficients respectively.

The expanded form of Equation 1 is:

$$I_c = J_c e^{-\beta_c^D(\boldsymbol{v}_D)\cdot z} + B_c^{\infty}(1 - e^{-\beta_c^B(\boldsymbol{v}_B)\cdot z}) \tag{2}$$

where,

z is the distance between the camera and objects in scene.

$\boldsymbol{B_c^{\infty}}$ is veiling light.

$\boldsymbol{J_c}$ is unattenuated scene.

Vector $\boldsymbol{v_D} = (z, \rho, E, S_c, \beta)$ represent dependency of $\beta_{\boldsymbol{c}}^{\boldsymbol{D}}$.

Vector $\boldsymbol{v_B} = (E, S_c, b, \beta)$ represent dependency of $\beta_{\boldsymbol{c}}^{\boldsymbol{B}}$.

- $\boldsymbol{\rho}$ is reflectance, **E** is spectrum of ambient light, $\boldsymbol{S_c}$ is spectral response of camera, **b** is physical scattering, $\boldsymbol{\beta}$ is beam attenuation coefficients of water body.

Sea-thru Method

- The Eq.2 depends on lot of parameters, therefore to recover $\boldsymbol{J_c}$ (unattenuated scene) the parameters need to be known or estimated.
- In Eq.2, $\beta_{\boldsymbol{c}}^{\boldsymbol{D}}$ wide-band coefficient is strongly dependent upon **z**, and $\beta_{\boldsymbol{c}}^{\boldsymbol{B}}$ back-scatter coefficient dependent upon the optical water type and illumination **E**.
- According to **Sea-thru** algorithm, the relevant parameters should be estimated from given image for that image only.

Imaging and Range Map

- As mentioned in Sea-thru paper, wide-band coefficient β_c^D largely depend upon z, so we required range map of the scene. (Scene as well as range map of the scene is given in the dataset)

Scene Reconstruction

- From above equation 1 and 2:

$$J_c = D_c e^{\beta_c^D(z) \cdot z} \tag{3}$$

where,

$$D_c = I_c - B_c \tag{4}$$

- **Approximation in 3rd equation:** As metioned above, wide-band coefficient β_c^D is largely depend on z, we will account z dependency and ignoring other dependencies.

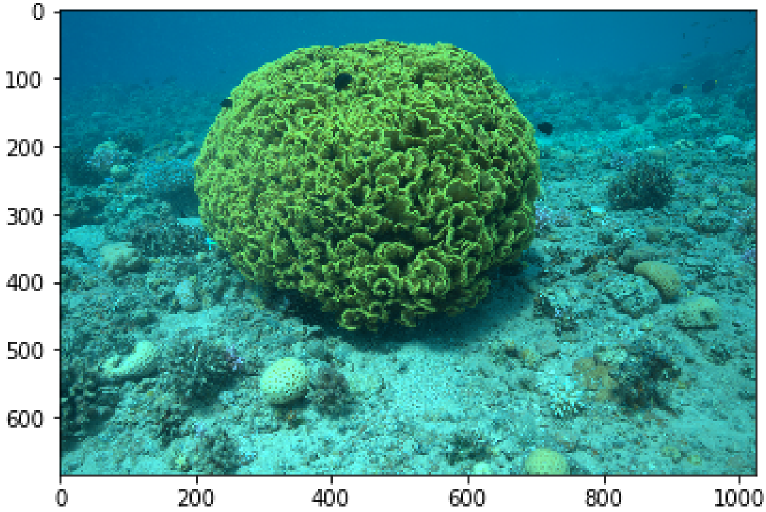
- $\boldsymbol{J_c}$ is image whose colors is **corrected along only in z-direction**, it need one more correction to achieve colors of an image that is taken at sea surface (this correction depends upon imaging geometry).
- $\boldsymbol{J_s}$ means image taken at surface:

$$J_s = J_c / W_c \tag{5}$$

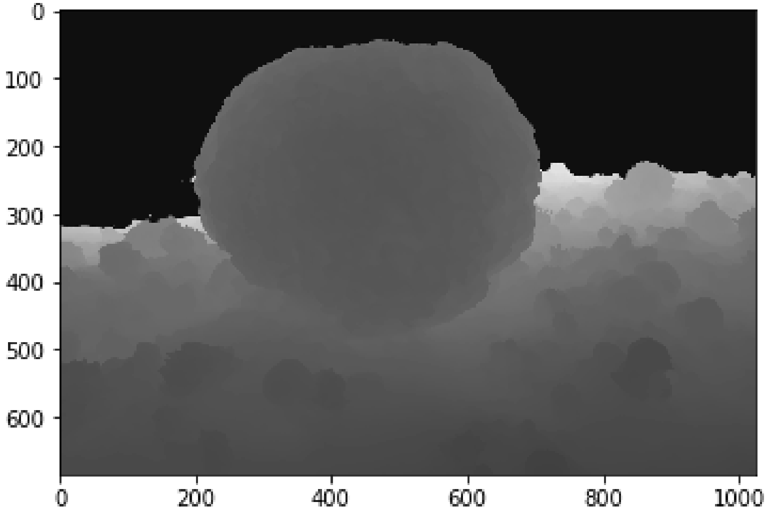
where,

$\boldsymbol{W_c}$=white point of ambient light at camera at depth d.
$\boldsymbol{J_s}$ is $\boldsymbol{J_c}$ globally white balanced.

Scene image



Range map of scene image



Back-Scatter Estimation

Backscatter increases exponentially with z and eventually saturates, at saturation, scene reflectance $\rho_c \rightarrow 0$ (all light absorbed), or $E \rightarrow 0$ (complete shadow) **the captured RGB intensity $\boldsymbol{I_c} \rightarrow \boldsymbol{B_c}$**.

Steps to follow for backscatter estimation (B_c) :

- First step, is to make the 10 equal cluster by partitioning the range map of scene.
- Second step, is to search RGB triplets which is in bottom 1 percentile (darkness) in I_c in each range clusters. And let it denote by Ω.
- By following above two steps, $\hat{B}_c(\Omega) \approx \mathrm{I}_c(\Omega)$ is an overestimate of backscatter. As mentioned above, $\boldsymbol{I_c} \rightarrow \boldsymbol{B_c}$.

contd...

Mathematics behind backscatter estimation:

$$\hat{B}_c = B_c^{\infty}(1 - e^{-\beta_c^B z}) + J_c' e^{-\beta_c^{D'} z} \tag{6}$$

- Second part of the above equation, as mentioned in paper it is small residual term that behaves like the direct signal.
- We will be calculating all the four parameters $(B_c^{\infty}, \beta_c^B, J_c', \beta_c^{D'})$ in above equation by using **least square fitting**.
- All four parameters is range bounded:
  - $\boldsymbol{B_c^{\infty}}$: [0, 1]
  - $\boldsymbol{\beta_c^{B}}$: [0, 5]
  - $\boldsymbol{J_c'}$: [0, 1]
  - $\boldsymbol{\beta_c^{D'}}$: [0, 5]

Result of Clustering

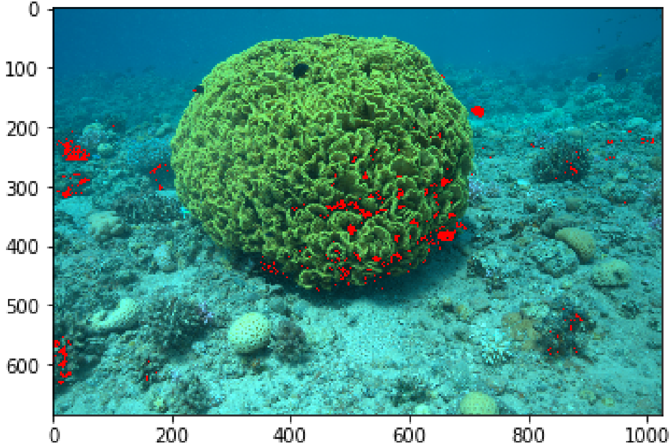


Figure: Clustering in 10 equal parts by partitioning the range map of scene.

Result of Backscatter Estimation

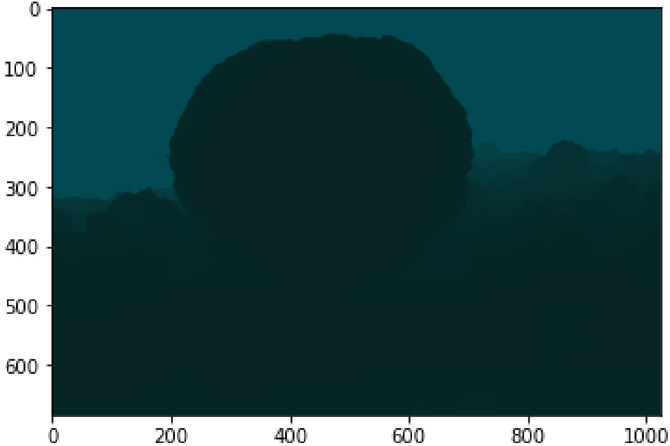


Figure: Estimated after calculating the parameters by using least square fitting.

Result after removing Backscatter from original image

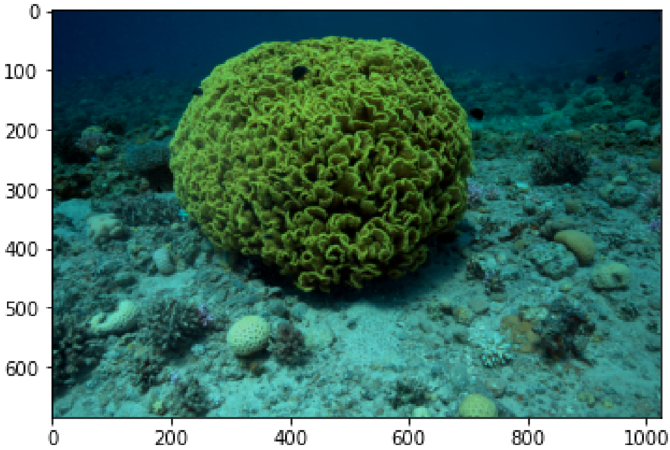


Figure: Backscatter removed by using the equation $D_c = I_c - B_c$.

$\boldsymbol{\beta_c^D}$ as a Function of z

- As mentioned in Sea-thru paper as well as above, $\boldsymbol{\beta_c^D}$ is strongly depends on z and its variation is in the form of exponential decay.
- According to experiment done by author, the proposed equation for dependence of $\boldsymbol{\beta_c^D}$ with z is:

$$\beta_c^D(z) = a * exp(b * z) + c * exp(d * z) \tag{7}$$

Coarse Estimate of $\boldsymbol{\beta_c^D}$ From an Image:

- As we know that, we know backscatter has been removed from image I_c

$$D_c = I_c - B_c \tag{8}$$

After removing backscatter, scene can be recover from the equation below:

$$J_c = D_c e^{\beta_c^D(z)z} \tag{9}$$

- From the two equation mentioned above, recovery of the scene now reduces to a problem of the estimation of the **illumiant map** between camera and scene, which varies spatially.
- Let Estimate of local illumiant map be $\hat{E}_c(z)$, we can obtain estimate of $\hat{\beta}_c^D(z)$ as follows:

$$\hat{\beta}_c^D(z) = -\log(\hat{E}_c(z))/z \tag{10}$$

- As backscatter is already removed from original image, we will be using the variant of the method called **local space over color (LSAC)**, as it utilizes range map.

The method of LSAC works as follows:
Given pixel (x, y) in color channel c and $a_c(x, y)$ is local space average color which will be estimated iteratively through updating the the below equation.

$$a'_c(x, y) = \frac{1}{N_e} \sum_{N_e} a_c(x', y') \tag{11}$$

$$a_c(x, y) = D_c(x, y)p + a'_c(x, y)(1 - p) \tag{12}$$

where,

N_e Neighbourhood is defined as the 4-connected pixels neighboring the pixel at (x, y) which are closer to it than a range threshold ϵ:

$$N_e(x', y') = (x', y') \textbf{ with } ||z(x, y) - z(x', y')|| \leq \epsilon \tag{13}$$

Points to consider while iterating the above equation:

- Initial value of a(x, y) is taken to be zero.
- The parameter p describes the local area of support over which the average is computed and depends on the size of the image.

The local illuminant map is found as $\hat{E}_c = fa_c$
where,

f = 2 in our case.

Refined Estimate of $\boldsymbol{\beta_c^D}$

We will be using known range map z to refine the estimate of $\boldsymbol{\beta_c^D}$ found from above mentioned equations. (Eq 10-13).

$$\hat{z} = -\log(\hat{E}_c(z))/\beta_c^D(z) \tag{14}$$

Using above equation which is rewritten from Eq 10 and minimize :

$$\min_{\beta_c^D(z)} ||z - \hat{z}|| \tag{15}$$

where,

- $\beta_c^D(z)$ defined in Equation 7 with parameters a, b, c, d.
- The bounds for parameters a, b, c, d to obtain a decaying exponential will be :
  Upper bounds: $[\infty, 0, \infty, 0]$
  Lower bounds: [-$\infty, 0, -\infty, 0]$

Scene can be recovered after finding $\boldsymbol{\beta_c^D(z)}$ using Eq. 9

Conclusion

- Sea-thru gives us the proof that β_c^D and β_c^B are distinct in water medium.
- Recovering the image using each dependencies is extremely challenging, deep nets can help us out in this.
- Sea-thru is a significant step towards opening up large underwater datasets to powerful computer vision and machine learning algorithms.

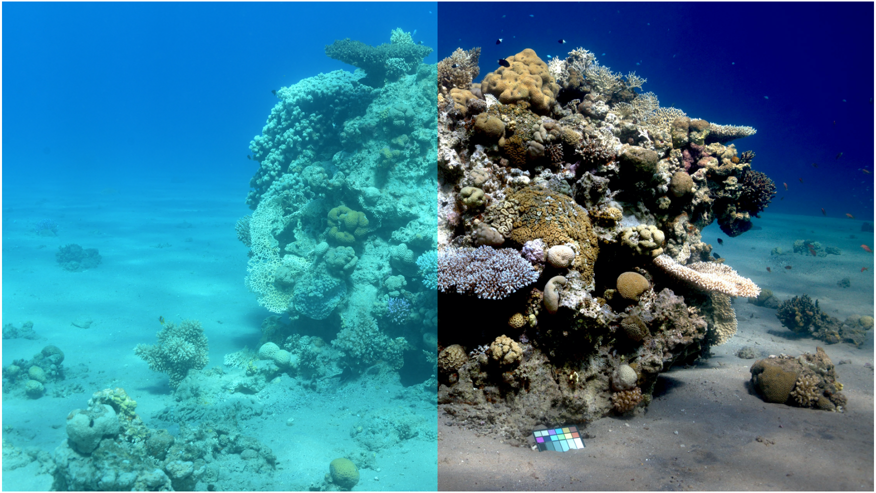


Figure: The **Sea-thru** method removes water from underwater images

References

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3. **Article:** https://towardsdatascience.com/sea-thru-removing-water-from-underwater-images-935288e
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